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PTO/SB/05 (08-00)
Approved for use through 10/31/2002. OMB 0651-0032
U.S. Patent and Trademark Office; U.S DEPARTMENT OF COMMERCE

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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	12001-102
First Inventor	Bharti Temkin
Title	HAPTIC RENDERING OF VOLUMETRIC.
Express Mail Label No.	EL377526811US

09/677073 09/29/00

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] Fee Transmittal Form (e.g., PTO/SB/17) *(Submit an original and a duplicate for fee processing)*
2. [X] Applicant claims small entity status. See 37 CFR 1.27.
3. [X] Specification [*Total Pages* 13] *(preferred arrangement set forth below)*
   - Descriptive title of the invention
   - Cross Reference to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to sequence listing, a table, or a computer program listing appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. [X] Drawing(s) *(35 U.S.C. 113)* [*Total Sheets* 3]
5. Oath or Declaration [*Total Pages* 3]
   a. [X] Unexecuted Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 CFR 1.63 (d)) *(for continuation/divisional with Box 17 completed)*
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. [ ] Application Data Sheet. See 37 CFR 1.76
7. [ ] CD-ROM or CD-R in duplicate, large table or Computer Program *(Appendix)*
8. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. [ ] Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] paper
   c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. [ ] Assignment Papers (cover sheet & document(s))
10. [ ] 37 CFR 3.73(b) Statement *(when there is an assignee)* [ ] Power of Attorney
11. [ ] English Translation Document *(if applicable)*
12. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
13. [ ] Preliminary Amendment
14. [ ] Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. [ ] Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. [X] Other: Post Card
    Statement Claiming Small Entity

17. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No.: ______/______

Prior application information: *Examiner* ______ *Group / Art Unit:* ______

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

18. CORRESPONDENCE ADDRESS

[ ] *Customer Number or Bar Code Label* *(Insert Customer No. or Attach bar code label here)* or [X] *Correspondence address below*

Name	Jerry Cohen				
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Name (Print/Type)	Jerry Cohen	*Registration No. (Attorney/Agent)*	20,522
Signature		*Date*	9/29/2000

PTO/SB/17 (12/99)
Approved for use through 09/30/2000. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

FEE TRANSMITTAL for FY 2000

Patent fees are subject to annual revision.
Small Entity payments must be supported by a small entity statement, otherwise large entity fees must be paid. See Forms PTO/SB/09-12. See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT ($) 345.00

Complete if Known	
Application Number	N/A
Filing Date	Herewith
First Named Inventor	Bharti Temkin, et al.
Examiner Name	N/A
Group / Art Unit	N/A
Attorney Docket No.	12001-102

METHOD OF PAYMENT (check one)

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 03-2410 Order No.: 12001-102

Deposit Account Name: Perkins, Smith & Cohen

Deficiencies Only

[X] Charge Any Additional Fee Required Under 37 CFR §§ 1.16 and 1.17

2. [X] **Payment Enclosed:**
[X] Check [ ] Money Order [ ] Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	345.00
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	690	208	345	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 345.00

2. EXTRA CLAIM FEES

		Extra Claims		Fee from below		Fee Paid
Total Claims	-20** =		X		=	
Independent Claims	- 3** =		X		=	
Multiple Dependent					=	

***or number previously paid, if greater; For Reissues, see below*

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim, if not paid
109	78	209	39	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	380	216	190	Extension for reply within second month	
117	870	217	435	Extension for reply within third month	
118	1,360	218	680	Extension for reply within fourth month	
128	1,850	228	925	Extension for reply within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	690	246	345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	690	249	345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) ____________________

Other fee (specify) ____________________

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	Jerry Cohen	Registration No. (Attorney/Agent)	20,522	Telephone	617-854-4000
Signature	[signature]			Date	9/21/00

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Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

Practitioner's Docket No. 12001-102
TTU D-0238

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Bharti Temkin and Jonathan R. Burgin

Application No.:
Filed on:
Title: HAPTIC RENDERING OF VOLUMETRIC SOFT-BODIES OBJECTS

STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) and 1.27(b)—NONPROFIT ORGANIZATION

I hereby state that I am an official empowered to act on behalf of the nonprofit organization identified below:

Name of Nonprofit Organization: Texas Tech University
Address: Technology Transfer and
Intellectual Property
Box 42007
Lubbock, Texas 79409-2007

TYPE OF NONPROFIT ORGANIZATION

University or Other Institution of Higher Education.

I hereby state that the nonprofit organization identified above qualifies as a nonprofit organization, as defined in 37 CFR 1.9(e), for purposes of paying reduced fees to the United States Patent and Trademark Office under Sections 41(a) and (b) of Title 35, United States Code, with regard to the invention described in the specification filed herewith, with title as listed above.

I hereby state that rights under contract or law have been conveyed to, and remain with, the nonprofit organization, with regard to the above-identified invention.

If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights to the invention is listed below and no rights to the invention are held by any person other than the inventor,

who would not qualify as an independent inventor under 37 CFR 1.9(c), if that person made the invention, or by any concern that would qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

No such person, concern, or organization exists.

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate (37 CFR 1.38(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 10001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

H. Walter Haeussler
Director
Technology Transfer and
Intellectual Property
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Texas Tech University
Lubbock, Texas 79409-2007

SIGNATURE [signature] Date Sept 25, 2000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
UTILITY PATENT APPLICATION

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POST OFFICE ADDRESS: c/o Texas Tech University Technology Transfer and Intellectual Property

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ASSIGNEE: Texas Tech University

INVENTION TITLE: **HAPTIC RENDERING OF VOLUMETRIC SOFT-BODIES OBJECTS**

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To: Honorable Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

Your applicants named above, hereby requests acceptance of the enclosed utility patent application.

TITLE

HAPTIC RENDERING OF VOLUMETRIC SOFT-BODIES OBJECTS

RELATED APPLICATIONS

The present application claims the benefits of U.S. Provisional Application Serial Number 60/156,852 filed on Sept. 30, 1999.

FIELD OF THE INVENTION

The present invention relates to processes and apparatus for interfacing force-feedback devices (and like data acquisition transducers) to computers, to add touchability to computers. The invention is more particularly associated with such touchability addition to the art of computer haptic rendering of three-dimensional soft-bodied objects.

BACKGROUND OF THE INVENTION

The interfacing of force-feedback devices (haptic interface devices) to computers adds touchability in computer generated interactions, called in the state of the art and herein, computer haptics. Two major components of computer haptics are collision detection of virtual objects with the haptic interface device, and the determination and display of appropriate force feedback to the user via the haptic interface device. Prior art data structures and algorithms applied to haptic rendering have been adapted from non-pliable surface-based (two dimensional) graphic systems. These prior art techniques and systems are sometimes inappropriate due to the different characteristics required for haptic rendering of three dimensional or volumetric soft bodies.

It is an object of the present invention to develop software and hardware suitable for haptic rendering of volumetric soft bodies.

It is a further object of the present invention to provide apparatus and processes for providing computer generated haptic renderings that accommodate the needs of volumetric soft bodies through recursive processes with efficient management of computational resources and viable process and apparatus choices.

A still further object of the present invention is to provide collision detection and deformation presentations along with appropriate force feedback to a user to provide virtual interactions of a stylus and a volumetric soft body.

It is still a further object of the present invention to provide a computer haptics process and apparatus that operates in real time.

SUMMARY OF THE INVENTION

The above objects are satisfied and other limitations of the prior art are overcome in the present invention through computer modelling and coding systems operating on economically obtainable and usable hardware and operating systems. The modelling/coding systems include:

1) haptic rendering of 3D volumetric objects using occupancy-map algorithm (OMA) for collision detection. [This is accomplished in the present invention as an advance over the known OMA used for solid non-deformable convex virtual objects]; and

2) chainmail algorithm (CMA) for generation of the real-time feedback forces while accommodating deformation of the soft-bodied object. [This is accomplished in the present invention as an advance on the known CMA used for calculating the behavior of convex surface virtual objects].

Minimum and maximums distances in three dimensions that a voxel (a 3D point with defined x, y, z coordinates relative to a defined vertex/center) can stably maintain with neighboring voxels are determined. Relative movement of the position

that a voxel takes relative to its center (while maintaining compliance with the minimum and maximum distances) is defined as "shear." When these minimums and maximums are violated a "collision" occurs, and the direction and relative forces can be inferred, so that such forces can be returned via a haptic device to the user. The minimum and maximum distances and the shears for all the voxels are adjusted to conform to the requirements and this calculation is carried out recursively until a stable state is evolved for all the voxels. In a preferred embodiment, the stable state is defined as a minimum energy state where distances are balanced among the voxels and the points are at the center or rest position with no shear. Such a minimum energy state calculation, per se, is well understood in the art.

An advantage of the present invention is that the characteristics of the voxels may be varied to model non-homogeneous soft bodies.

The physical parameters of the materials involved are known in the art, so that the deformation, resistance to forces and penetration and/or bouncing can be modelled, as is known in the art.

Using the improved versions of these techniques overcomes the limitations of the haptic prior art when applied to volumetric soft-bodied objects.

Another aspect of the present invention allows for the penetration of a soft three-dimensional body while maintaining proper force feedback by use of a proxy form of the penetrating body, a stylus in an embodiment. In yet another aspect of the present invention provision is made for the bouncing of one body after colliding with another.

Other objects, features and advantages will be apparent from the following detailed description of preferred embodiments taken in conjunction with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram of the chainmail model for the nearest neighbor distance;

Figure 2 is a diagram of the chainmail model for shear;

Figure 3 is a representation of the haptic rendering of an object being penetrated;

Figure 4 represents the object of Figure 3 but with the addition of a proxy; and

Figure 5 is a representation of bounce from a surface when a strong force is used.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 illustrates the model used for determining touching or collisions between a haptic interface device and a virtual object. This is a first step of haptic interaction with virtual objects. In a haptic virtual reality system (HVRS) an interaction with a virtual object is done by "touching" the object using a haptic interface device - a stylus, and feeling the force feedback through the haptic device just as if the object were touched in reality. A real-time operation of a HVRS is necessary to be useful (it is evident that time delays would make the system useless), and real time operation requires efficient collision detection. The present invention provides such efficient collision detection.

The virtual environment and virtual objects are stored in memory in a three dimensional array called an occupancy map. When the occupancy map is initialized, each position in the map is set to –1 meaning that position is unoccupied. When a virtual object is added to a scene defined by the occupancy map, the appropriate positions in the occupancy map are set to 0. The borders of the virtual scene follow

this same pattern as well. Other such encoding/modelling schemes, known in the art, can be also used to advantage.

The chainmail algorithm operates in a manner similar to the movements of a chained armor regarding the individual linked pieces of the armor relative to its neighbors. With reference to Figure 1, a "voxel" is herein defined a three dimension (3D) volumetric "point" 2 which represents one piece of chain mail that is linked to its nearest neighbors 4 in three dimensions. It should be noted that a neighbor may be along a positive or negative direction on the three axes; therefore there may be up to six such nearest neighbors. Figure 1 illustrates the minimum and maximum distances that a voxel and its linked neighboring voxels are allowed to move maintaining stability. In each of the three dimensions there is an minimum 6 and an allowable maximum 8 axis location defining an allowed delta position relative to the position of the voxel 2 under consideration. Once the occupancy map algorithm, OMA, determines a collision, the chainmail algorithm, CMA, determines the geometry of the neighboring vertices including the direction(s) of the movements. With respect to Figure 2, "shear" herein is measured by the positive or negative delta 10 (difference) in position of the voxel under consideration compared to its neighbors along each of the three axes. With respect to Figures 1 and 2, whenever the minimum 6 or the maximum 8 distances or shear distances are violated, the neighboring voxels are adjusted to compensate for the discrepancy so that the entire array of voxels meet the minimum and maximum deltas for position and shear. The process is recursively implemented until all the voxels in the system reach stability, i.e. meet the minimum, maximum deltas for position and shear criteria for the x, y and z directions.

When a collision occurs the relative positions of the voxels that violate the minimums and maximums of position and shear are used to determine the direction and force of the collision. The recursive nature of changing the relative positions of the

voxels to meet the minimums and maximums for positions and shear cause the three dimensional object to distort in response to the direction and size of the colliding voxels, as is known in the art.

At any given time, the position of the haptic stylus and the occupancy map are used to determine a collision between the voxel at that position and the stylus tip. Furthermore, the direction of approach and "chain mesh"(the actual distances and deltas described above for position and shear) of the CMA are taken into account to resolve the collision with "ripple effects of other voxels" and the deformation (relative movement of the voxel) that occurs due to the collision.

In a preferred embodiment the haptic device is the PHANToM® stylus which is well known in the art. In this system the software assumes the stylus is a point that interacts with an object as described with the occupancy map. In this system the force feedback on the haptic interface device is developed by the computer system as a function of the distance from the stylus point to the nearest surface. Modifying the surface based graphic haptic systems results in at least two major problems that must be overcome. One such problem occurs when the stylus approaches through penetration of an object. Care must be made to assure that the force which is presented by the computer system to the haptic device penetrates an object's surface and approaches the opposite surface remains in the proper direction as well as the proper magnitude. Figure 3, illustrates this problem. The stylus 20 collides with the surface 21. The force 22 is directed by the computer system onto the haptic interface so that the user feels the force resisting penetration of the surface. But, as the stylus approaches the opposite surface 26, the force reverses direction 24 since the direction is computed with reference to surface 26, as if the stylus is penetrating that surface from the opposite direction. Figure 4 illustrates a solution to this problem. Here a proxy stylus is created colliding with the surface. The virtual stylus continues to

penetrate the object just shown in Figure 3, but the proxy provides a continuous force 28A, 28B, and 28C that is applied to the haptic device that resists the continued penetration of the stylus as the stylus approaches the opposite surface. The second problem exists with some volumetric rendering software techniques when the contact is momentarily lost if the force is strong enough to bounce the point stylus away from the surface, although the user is still pushing towards the surface. The net effect is that the stylus position and the surface voxel pass through each other losing contact with each other. In such a case the voxel relaxes outward towards its original location. This loss of contact might result in no force feedback to the haptic device and no pressure against the surface. Figure 5 illustrates this problem. The user pushes the proxy (stylus) 30 with a hard force 31 against the voxel 32 which provides a resisting force 34 to the haptic device. The surface deforms and bounces away 38 from the proxy and there is no resisting force and no force on the voxel 32. The user continues pushing and the proxy penetrates beyond the rest position of the voxel 32. With no force on it, the voxel 32 relaxes back to its rest position 36. At this point the proxy has penetrated the surface but the voxel 36 surface is intact - this represents an erroneous operation. To help resolve this problem, the collision is checked at the location of the proxy and at the six directional points at a fixed radius distance from the proxy until the contact is made with a voxel whereupon the proper deformations and forces feedback via the haptic device to the user are established.

A related problem occurs with the voxel relaxing as described above. The virtual computing system must provide a damping action to the relaxing where the relaxing incurs only a small amount of vibration. Without this damping the vibration will not end and is visually disturbing.

The system software can accommodate non-homogeneous behavior and response of the material within the soft bodies. This is accomplished by programming

the force feedback resisting penetration of the bodies by a stylus. The density, resilience, viscosity, elasticity, and other physical parameters of the material or materials and can be modelled in the software to realistically react to different interactions of non-homogeneous materials and the stylus.

As discussed above many computing systems can be used to implement the present invention. In a preferred embodiment, a 266 MHz PC running the NT operating system, twelve megabytes for representing 11,200 polygons (voxels) was implemented. However, other computing systems, such as known in the art, including distributed systems and other operating systems can be used to advantage.

While the above description shows utilization of a family of disclosed special form OMA-CMA systems of the invention to deal with force-feedback in haptic rendering and analysis of soft body objects and conditions thereof, the systems of the invention, including the computer modelling and coding techniques thereof, can also be applied to other analogous situations of varying feedback intensity of measured or computed electronic, optical and magnetic responses associated with soft body volumes. The present invention incorporates such alternate usages.

It will now be apparent to those skilled in the art that other embodiments, improvements, details, and uses can be made consistent with the letter and spirit of the foregoing disclosure and within the scope of this patent, which is limited only by the following claims, construed in accordance with the patent law, including the doctrine of equivalents.

We claim:

CLAIMS

1. A process for haptic rendering of three-dimensional soft bodied objects for virtual interactions comprising the steps of:

forming a three dimensional occupancy map of voxels, forming the surface and bound the object,

forming a multi-dimensional coordinate system for each point, the coordinate system defining a vertex center,

defining minimum and maximums distances of one voxel to all its neighboring voxels (occupied neighbor points),

defining multi-dimensional maximum offsets that an occupied point can maintain relative to its center,

detecting when the minimums or maximums of distance and/or offsets are violated, and in response thereto

moving the points in violation to locations relative to the neighboring occupied points and the points' centers that satisfy the minimum and maximum for distance and offsets,

repeating the detecting and moving steps for the entire occupancy map until there are essentially no violations.

2. The process as defined in claim 1 further comprising determining a minimum energy state for all occupied points, and continuing the repeating of the detection and moving steps until the entire object is at a minimum energy state.

3. The process as defined in claim 1, further comprising the steps of determining, from the relative moving of the points and the offsets from the center for each point, the direction and size of the force of the colliding bodies, and delivering that force in size and direction via a haptic device.

4. The process as defined in claim 1, wherein when one body collides with and penetrates or bounces from another, further comprising the steps of:

forming a proxy of the penetrating or bouncing body that maintains its position on the surface, and wherein the moving of the points responds to the proxy as well as the penetrating body.

5. The process as defined in claim 1 further comprising damping the responses of the points as collisions occur.

6. An apparatus for haptic rendering of three-dimensional soft bodied objects for virtual interactions comprising tin combination:

means for forming a three dimensional occupancy map of voxels, forming the surface and bound the object,

means for forming a multi-dimensional coordinate system for each point, the coordinate system defining a vertex center,

means for defining minimum and maximums distances of one voxel to all its neighboring voxels (occupied neighbor points),

means for defining multi-dimensional maximum offsets that an occupied point can maintain relative to its center,

means for detecting when the minimums or maximums of distance and/or offsets are violated, and in response thereto

means for moving the points in violation to locations relative to the neighboring occupied points and the points' centers that satisfy the minimum and maximum for distance and offsets, and

repeating the detecting and moving steps for the entire occupancy map until there are no violations.

7. The apparatus as defined in claim 1 further comprising means for determining a minimum energy state for all occupied points, and for continuing the

repeating of the detection and moving steps until the entire object is at a minimum energy state.

8. The apparatus as defined in claim 1, further comprising the means for determining, from the relative moving of the points and the offsets from the center for each point, the direction and size of the force of the colliding bodies, and for delivering that force in size and direction via a haptic device.

9. The apparatus as defined in claim 1, constructed and arranged so that when one body collides with and penetrates or bounces from another, and a proxy of the penetrating or bouncing body is formed that maintains its position on the surface, and so that wherein the moving of the points responds to the proxy as well as the penetrating body.

10. The apparatus as defined in claim 1 further comprising means for damping the responses of the points as collisions occur.

ABSTRACT

Haptic rendering of three-dimensional soft bodied objects for virtual interactions implemented by forming a three dimensional occupancy map of voxels, forming the surface of and bounding an object, forming a multi-dimensional coordinate system, defining minimum and maximums distances of one voxel neighboring voxels

defining multi-dimensional maximum offsets that an occupied point can maintain relative to its center, detecting when the minimums or maximums of distance and/or offsets are violated, and in response thereto adjusting to satisfy minimum and maximum for distance and offsets, and repeating the detecting and adjustment steps for the entire occupancy map until there are essentially no violations.

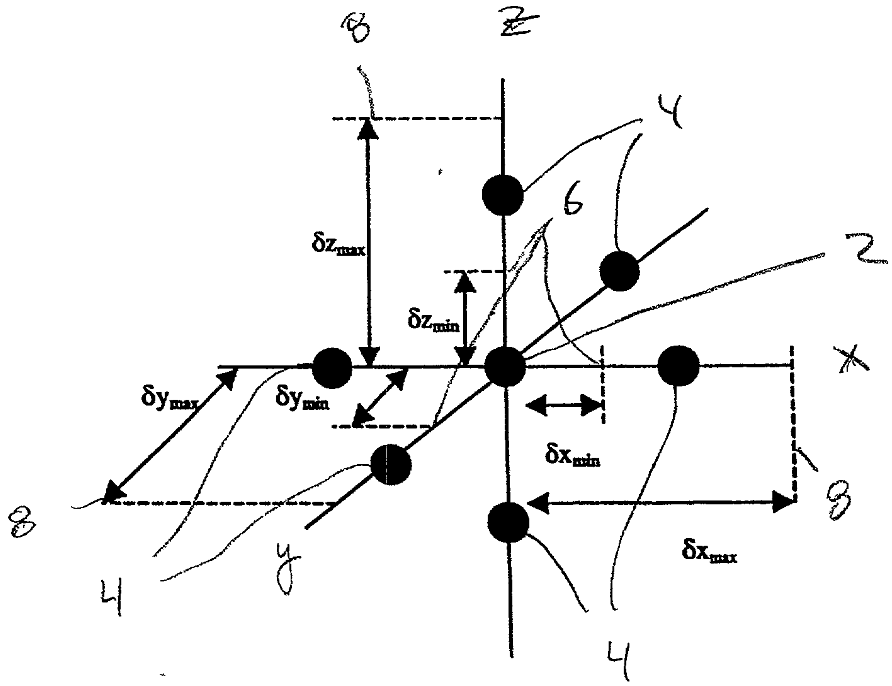

Figure 1

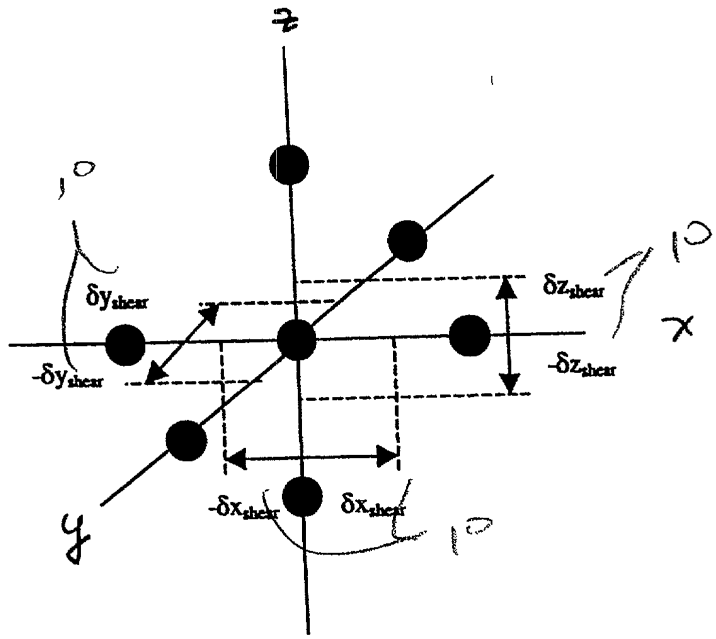

Figure 2

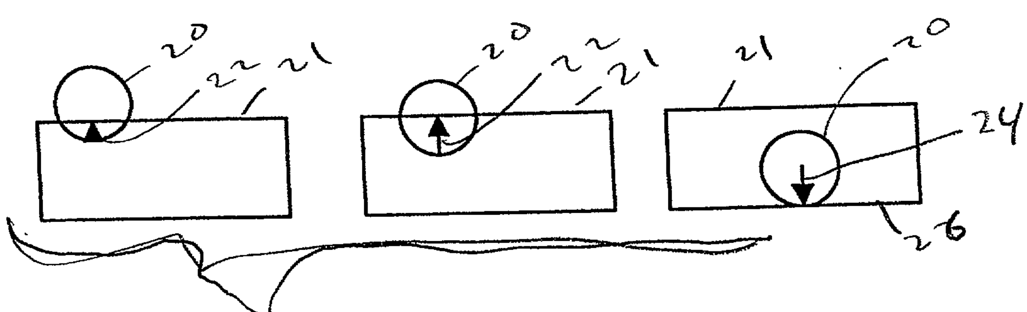

Figure 3

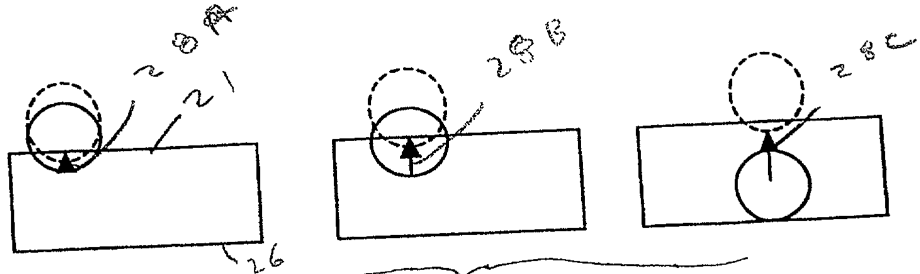

Figure 4

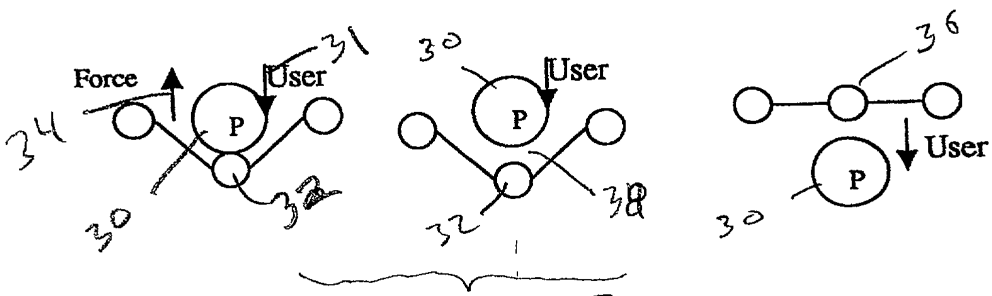

Figure 5

Please type a plus sign (+) inside this box → [+]

PTO/SB/01 (12-97)
Approved for use through 9/30/00. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

Attorney Docket Number	12001-102
First Named Inventor	Bharti Temkin
COMPLETE IF KNOWN	
Application Number	/
Filing Date	Herewith
Group Art Unit	N/A
Examiner Name	N/A

☒ Declaration Submitted with Initial Filing **OR** ☐ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled.

HAPTIC RENDERING OF VOLUMETRIC SOFT-BODIES OBJECTS

(Title of the Invention)

the specification of which

☒ is attached hereto

OR

☐ was filed on (MM/DD/YYYY) [ ] as United States Application Number or PCT International Application Number [ ] and was amended on (MM/DD/YYYY) [ ] (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
60/156,852	09/30/1999	☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

Please type a plus sign (+) inside this box → [+]

PTO/SB/01 (12-97)
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DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith ☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*
OR
☒ Registered practitioner(s) name/registration number listed below

Name	Registration Number	Name	Registration Number
Jerry Cohen	20,522	Jacob N. Erlich	24,338
Harvey Kaye	18,978	Christine M. Kuta	38,001
Stephen Y. Chow	31,338	Chester A. Bisbee	44,538

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto

Direct all correspondence to: ☐ Customer Number or Bar Code Label [ ] OR ☒ Correspondence address below

Name	Jerry Cohen, Esq.				
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Address	One Beacon Street, 30th Floor				
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Bharti	Temkin

Inventor's Signature						Date	
Residence: City	Ransom Canyon	State	TX	Country	USA	Citizenship	US
Post Office Address	c/o Texas Tech University Technology Transfer and Intellecutal Property						
Post Office Address	P.O. Box 42007						
City	Lubbock	State	TX	ZIP	79409-2007	Country	USA

☒ Additional inventors are being named on the ____ supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 1

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor						
Given Name (first and middle [if any])	Jonathan R.			Family Name or Surname	Burgin		
Inventor's Signature						**Date**	
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City	Lubbock	**State**	TX	**ZIP**	79409	**Country**	USA

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor						
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature						**Date**	
Residence: City		**State**		**Country**		**Citizenship**	
Post Office Address							
Post Office Address							
City		**State**		**ZIP**		**Country**	

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor						
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature						**Date**	
Residence: City		**State**		**Country**		**Citizenship**	
Post Office Address							
Post Office Address							
City		**State**		**ZIP**		**Country**	

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